

RESEARCH NOTE 80-5

LEVEL #2

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A FRAMEWORK FOR IDENTIFYING HUMAN FACTORS RESEARCH NEEDS IN COMMAND AND CONTROL

Seth Bonder, W. Peter Cherry, and Robert L. Farrell
Vector Research, Incorporated

HUMAN FACTORS TECHNICAL AREA

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MARCH, 1980

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER Research Note 80-5	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) A Framework for Identifying Human Factors Research Needs in Command and Control		5. TYPE OF REPORT & PERIOD COVERED Final Report 7/16/79 - 1/23/80
6. AUTHOR(s) Seth Bonder, W. Peter Cherry, Robert L. Farrell		7. PERFORMING ORG. REPORT NUMBER VRI-ARI-4-FR80-1
8. CONTRACT OR GRANT NUMBER(s) MDA903-79-C-0324		9. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 2Q762722A765
10. CONTROLLING OFFICE NAME AND ADDRESS Deputy Chief of Staff for Personnel Washington, DC 20310		11. REPORT DATE March 1980
12. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) US Army Research Institute for the Behavioral and Social Sciences 5001 Eisenhower Avenue Alexandria Virginia 22333		13. NUMBER OF PAGES 88
14. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited (18) ARI (19) RN-20-5		15. SECURITY CLASS. (of this report) Unclassified
16. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report) Final Rept. 16 Jul 77-13 Jan 80		17. DECLASSIFICATION/DOWNGRADING SCHEDULE
18. SUPPLEMENTARY NOTES Edgar M. Johnson and Stanley M. Halpin provided valuable review of the framework and estimates of the available command and control knowledge.		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Human Factors/Command and Control (HF/C ²) HF/C ² Activities HF/C ² Knowledge Areas Types of HF/C ² Research		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This effort developed a framework to assist in identifying human factors research areas in command and control (HF/C ²) of importance to the Army. It is a systems-oriented framework that considers HF/C ² activities needed to assist in developing Army systems and HF/C ² knowledge required/available to generate a menu of potential HF/C ² research needs by type of research (Application Demonstration, Applied Research, and Exploratory Research). The framework also provides information regarding the time when the research output will be of first use to the Army.		

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Department of the Army

MARCH, 1980

Army Project Number
2Q762722A765

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CONTENTS

<u>Section</u>	<u>Page</u>
1.0 INTRODUCTION	1-1
2.0 ROLE/INFLUENCE OF MILITARY HF/C ²	2-1
3.0 HF/C ² FRAMEWORK	3-1
4.0 KNOWLEDGE AREAS IN HF/C ²	4-1
4.1 Command and Control: A Functional Paradigm	4-1
4.2 HF/C ² Knowledge and Knowledge Factors	4-5
4.2.1 Functional Requirements, Functional Specifications and Design Knowledge Factors . .	4-6
4.2.2 Performance Evaluation and Prediction Knowledge Factors	4-8
4.3 Current Availability of Knowledge	4-13
5.0 EXAMPLE FRAMEWORK APPLICATION TO IDENTIFY HF/C ² RESEARCH EFFORTS	5-1
5.1 Research Program Development Process	5-1
5.2 Sample Application of the Process for ASAS	5-6
5.3 Presentation of Proposed Program	5-16
6.0 GENERAL COMMENTS	6-1
APPENDIX	A-1

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EXHIBITS

<u>Number</u>	<u>Title</u>	<u>Page</u>
2-1	System Acquisition Cycle	2-2
2-2	Timing of the HF/C ² Roles in the System Acquisition Relationship	2-5
2-3	Life Cycle Cost Decisions	2-7
3-1	Required HF/C ² Roles for Some Army Battlefield Automated Systems	3-4
3-2	Framework for Identifying HF/C ² Research Needs	3-8
4-1	Command and Control: A Functional Paradigm	4-3
4-2	Command and Control Tasks: Common Pertinent Knowledge Factors	4-10
4-3	Performance Evaluation: Pertinent Knowledge Factors	4-11
4-4	Performance Prediction: Pertinent Knowledge Factors	4-12
4-5	Availability of Knowledge	4-16
5-1	Framework for Identifying HF/C ² Research Needs	5-2
5-2	Determining Type of ARI HF/C ² Effort	5-5
5-3	Sample Worksheet -- Functional Requirements Role	5-8
5-4	Sample Worksheet -- Design Role	5-12
5-5	ARI HF/C ² System Program - Overall Systems Relevance -	5-18
5-6	ARI HF/C ² System Program - Relevance to System S _i -	5-19

EXHIBITS
(Concluded)

<u>Number</u>	<u>Title</u>	<u>Page</u>
5-7	ARI HF/C ² System Program - Costs by Functional System Type -	5-20
5-8	ARI HF/C ² System Program - Costs by System Acquisition Phase -	5-21
5-9	ARI HF/C ² System Program - Costs by HF/C ² Role (Influence) -	5-22
5-10	ARI HF/C ² System Program - Cost by Type of Effort -	5-23
5-11	ARI HF/C ² System Program - Cost by First Use Horizon -	5-24
5-12	ARI HF/C ² Non-System Program	5-25

1.0 INTRODUCTION

Vector Research, Incorporated, (VRI) performed a small study for the Army Research Institute (ARI) to assist in identifying human factors research areas in command and control (hereafter referred to as HF/C²) of importance to the Army. This objective was accomplished by performing three tasks:

- (1) reviewing related HF/C² literature,
- (2) identifying approaches to evaluate C² activities/systems,
and
- (3) developing a framework which could be used to identify
important areas of HF/C² research,

with primary emphasis on the third one. This report documents the results of the study.

The report is comprised of six sections, including this introductory one, and an appendix. Section 2.0 discusses the role and activities of behavioral analysis/science in Army planning and operations since it is these activities which (should) motivate ARI's research programs in general and the HF/C² ones in particular. A principal activity in identifying HF/C² research areas was the structuring of a framework or paradigm which highlights dimensions relevant to the development and use of HF/C² information for the Army. The dimensions of such a framework are described in section 3.0. We believe the framework will be useful, not only as a vehicle for continual identification of research areas, but also as a means of demonstrating the relevance of ARI programs to the Army and of providing underlying rationale for ARI research and analysis budgets. One of the dimensions -- HF/C² knowledge areas -- is

described in more detail in section 4.0, along with initial subjective estimates of the degree of HF/C² knowledge available. Section 5.0 demonstrates how the framework and available HF/C² knowledge are used to identify potential ARI research efforts in HF/C². Some general comments regarding ARI's HF/C² activities are given in section 6.0. The appendix discusses approaches that might be used to evaluate C² activities and systems.

Before proceeding on this itinerary, it is useful to set the scope of the content area considered in this study. (Section 4.0 details the area by delineating some of its inherent substance.) Human factors are concerned with the application of psychological and physiological principles to the design, development, and use of complex man-machine systems. It is taken to encompass substance considered under many previous titles such as human engineering, experimental psychology, biotechnology, psychotechnology, and others created as the discipline grew from the major impetus of World War II. HF/C² is the application of this branch of behavioral science to military "systems"¹ that involve command and control.² This is broadly concerned with processes involving the collection of information, human assimilation of information, decision-making, and the communication/dissemination of the decisions. Although these processes are generally thought of as occurring in C² systems

¹The term system is used in a broad sense to include materiel, organization, and procedures necessary for an operational Army entity, recognizing that some systems are more materiel oriented and others more organizational and procedural.

²The authors believe that there does not exist a widely accepted and operationally useful definition of command and control. (A formal definition is contained in JCS Publication #1.) Nor are we foolish enough to attempt to create one. We are confident that readers interested in this study are aware of many realizations of existing and planned C² systems and systems that require C².

such as a Tactical Operations Center (TOC) or the All Source Analysis System (ASAS), it should be recognized that they also occur in other Army systems such as PATRIOT, Corps Support Weapon System (CSWS), Division-86, Pershing II, an XM-1 tank platoon, and the infantry squad which require different levels and degrees of command and control to be operationally effective.¹ In essence, command and control is pervasive throughout most of the Army's systems and will continue to be so as new technologies create the environment for short, high-attrition engagements and campaigns requiring reduced spatial densities and rapid mobility.

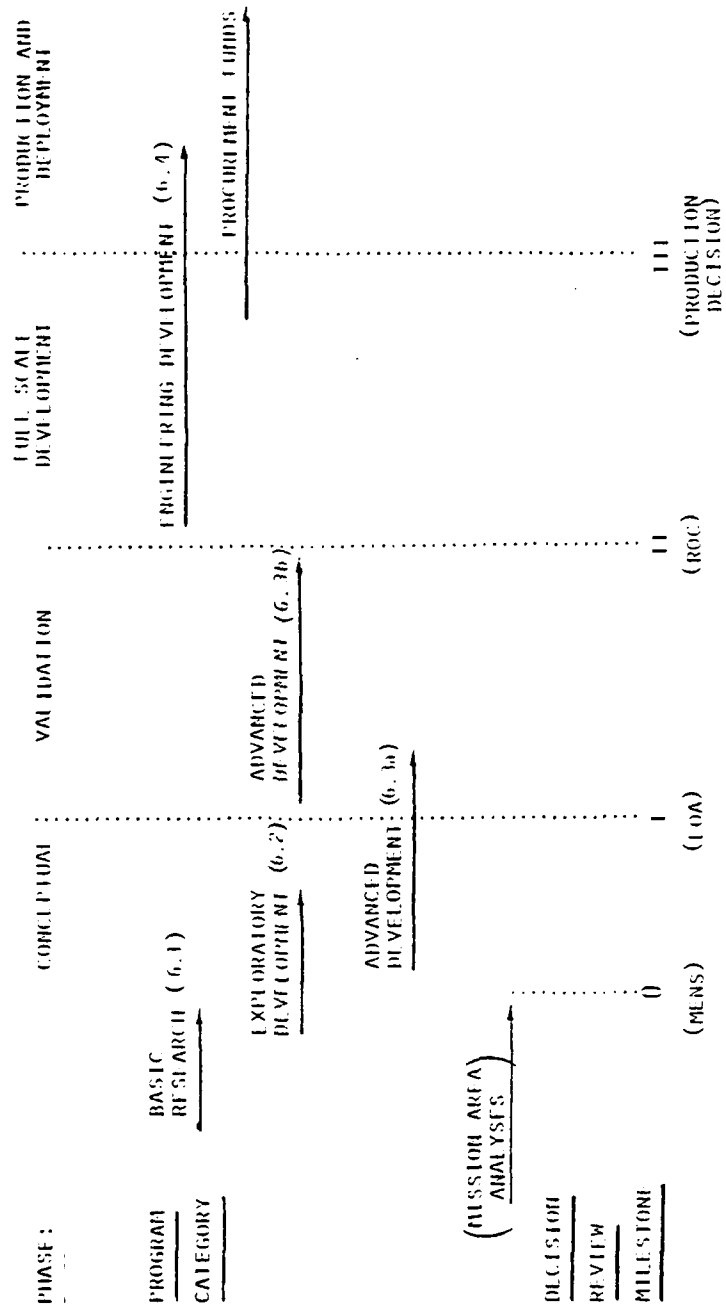
¹Although Army regulations on the subject are not completely definitive, it appears that the Human Engineering Laboratory (HEL) is concerned with the man-machine interface problem for operation of Army systems and the ARI with the organizational and procedural aspects for users of such systems.

2.0 ROLE/INFLUENCE OF MILITARY HF/C²

The overall objective of military HF/C² is to enhance the performance of command and control in Army systems. This is accomplished by performing a number of roles related to the design, development, and use of C² components of systems. Since the degree to which these roles are performed by ARI behavioral scientists strongly influences how well the Army, per se, will perform, these roles are sometimes referred to as "influences" in this paper. The better the roles are performed, the more influence ARI has on helping the Army accomplish its missions. The purpose of this section of the report is to summarize the roles or influences of HF/C² in the Army.

As noted above, the overall objective of military HF/C² is to enhance performance of the command and control aspects in systems. Thus ARI's HF/C² programs should influence Army systems as they proceed through the acquisition cycle which is shown in exhibit 2-1. The development of a new system is initiated by the preparation of a Mission Element Needs Statement (MENS), a Letter of Agreement (LOA) at the end of the conceptual phase, and then a Required Operational Characteristics (ROC) at milestone II. These documents essentially delineate objectives that are to be accomplished with the system which drive much of the remainder of the development, production and deployment processes. The influence of HF/C² in this process should begin in the early conceptual phase and continue through the system's development by developing HF/C² knowledge, methods, and procedures and guiding their implementation to accomplish the following activities in the acquisition process:

EXHIBIT 2-1: SYSTEM ACQUISITION CYCLE



- HF/C² functional requirements,
- HF/C² functional specification,
- HF/C² design,
- HF/C² performance evaluation, and
- HF/C² performance prediction.

The MENS, LOA, and ROC delineate objectives to be accomplished by the system. The functional requirements role of HF/C² is one in which the C² functions that must be performed to accomplish the system's objectives are identified.¹ Additionally, the inputs, processes, outputs, and required performance standards for each of the functions and constituent tasks need be determined for each component of the system. In essence, this role influences what C² functions need to be performed.

In the functional specification role, alternative means of accomplishing each of the C² functions, and tasks are broadly evaluated leading to the specification of who or what is to perform the functions, and to some extent how to perform them. Examination of alternatives considers performance of functions by:

- the system itself or by exogenous entities;
- manual, semi-automated, or automated approaches; and
- single or multiple tasking of individuals or groups.

For example, order of battle estimates can be organized by geographic area, by intelligence collection system, or by type of threat unit. The

¹In practice, this is not an HF/C² role, per se, but rather one that is performed by operational personnel, perhaps with the assistance of behavioral scientists to provide guidance on feasibility of achieving the requirements.

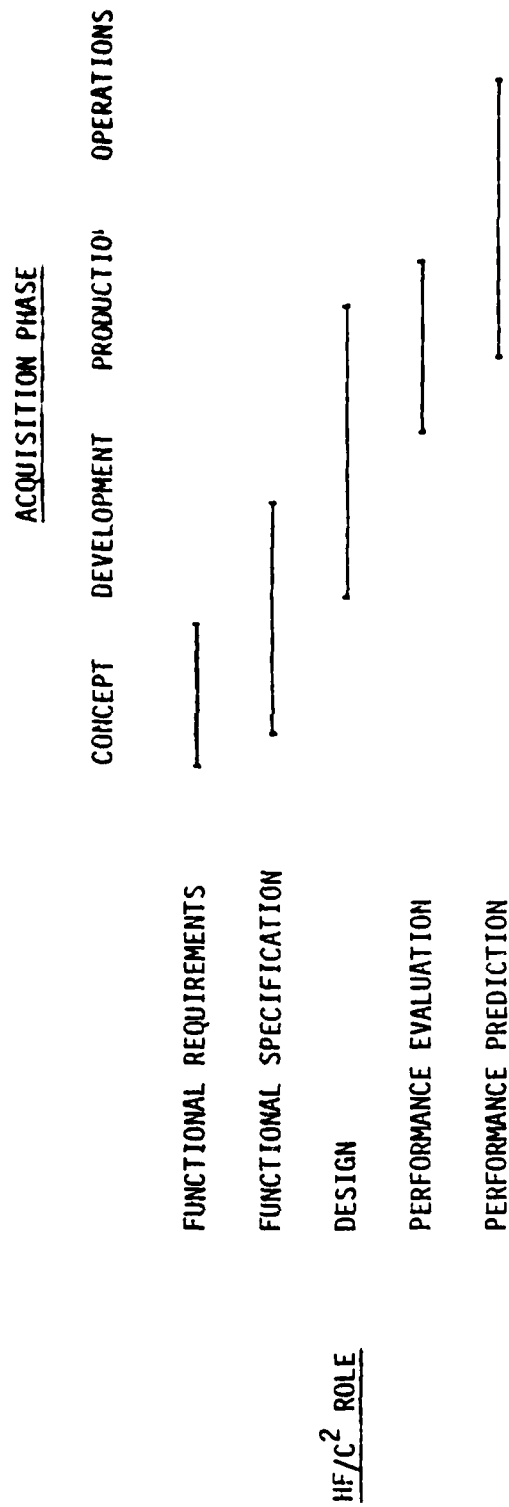
evaluation and selection of particular approaches considers broad estimates of associated resource requirements (funds and personnel), feasibility of achieving required performance standards, the effects that operational environments may have on these evaluation factors, and requirements for redundancy.

Given the functional requirements and specification of the approach to be used to achieve them, a major role of HF/C² is to influence the design of principal C² components of the system. This includes influencing detailed design of the C² (or C² related) tasks to be performed by individuals or groups of individuals; design of the organization(s) necessary to operate the system; design of C² materiel¹ or materiel aids intended to support the C² function; and the design of efficient individual and organizational training to insure effective C² when the system is deployed.

The role of performance evaluation is concerned with measuring the degree of individual proficiency and overall effectiveness of the C² function associated with the system. Performance prediction is concerned with testing the potential of individuals and groups of individuals to accomplish required C² tasks, and the selection of system personnel based on the test results. Recognizing that evaluation and prediction are done by other components of the Army, the role of HF/C² is to design instruments for evaluation and prediction and provide guidance on their use.

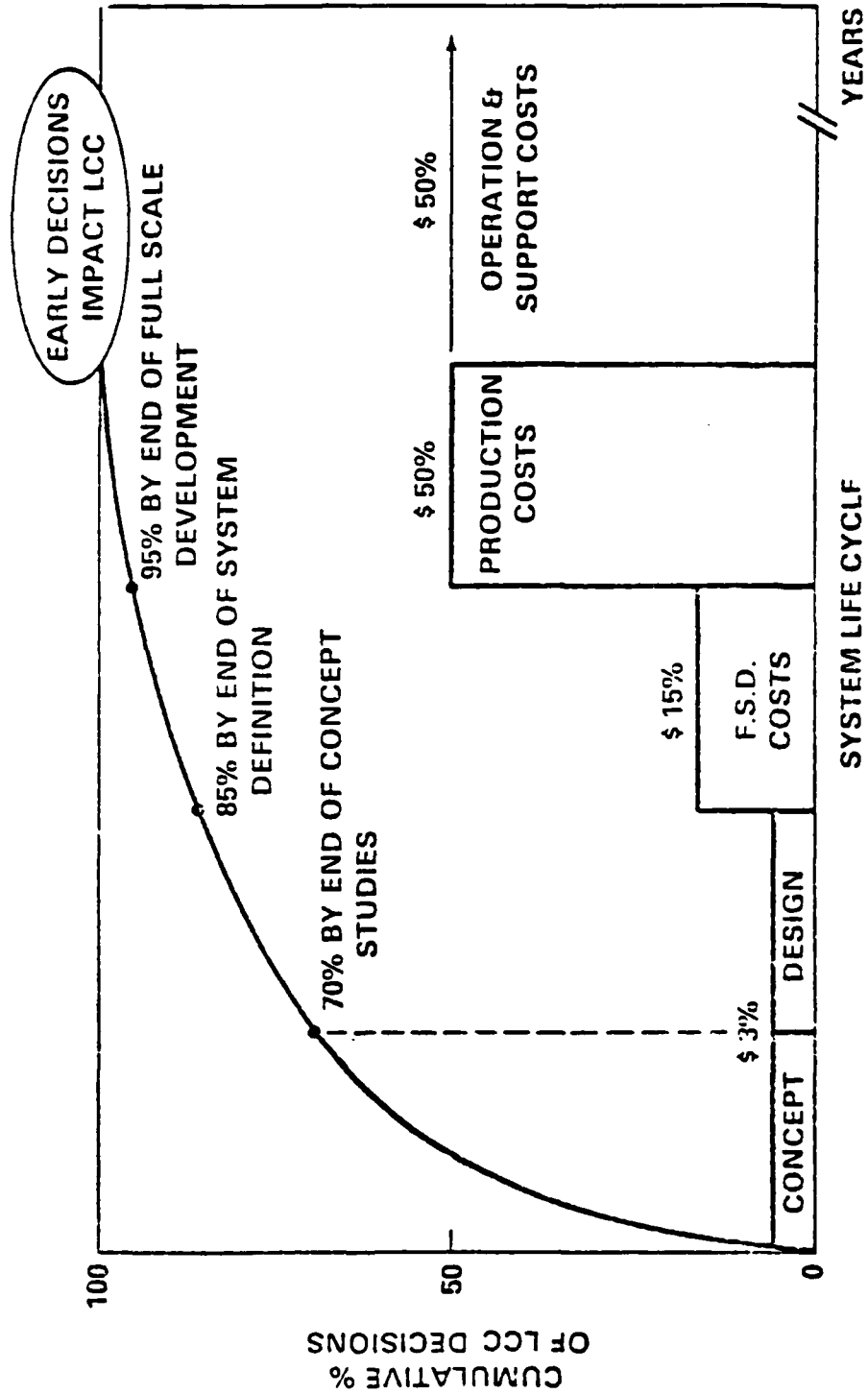
Conceptually, these roles or influences of HF/C² occur at different phases of a system's acquisition as indicated in exhibit 2-2.

¹A significant portion of the human factors guidance on material design and man-machine interfaces is performed by the Army's Human Engineering Laboratory.

EXHIBIT 2-2: TIMING OF HF/C² ROLES IN THE SYSTEM ACQUISITION RELATIONSHIP

We have taken the liberty of referring to the validation and full scale development phases as the "development" phase. Although this exhibit reflects sequential HF/C² influences on a system's development, in practice there is (or should be) continual feedback and interaction among them. Additionally the relationship reflected in exhibit 2-3 suggests that the HF/C² influence should occur early in a system's development since decisions made by the completion of Acquisition Milestone I appear to have a significant impact on the system's life cycle costs. The fact that (a) the Army always has many systems in each of the acquisition cycle phases, and (b) a system's effectiveness is highly dependent on achieving good C² performance (be it a weapon system, a support system, or a C² system per se), strongly suggests that HF/C² efforts can and should have a pervasive influence on the Army.

EXHIBIT 2-3: LIFE CYCLE COST DECISIONS



3.0 HF/C² FRAMEWORK

This section of the report outlines a framework for determining human factors research and analysis needs in the area of command and control. It is a systems-oriented framework to depict where the HF/C² research programs have an influence on the Army, and to suggest that ARI's research program should be developed with a systems perspective to insure its relevance. This is not to suggest that the total ARI HF/C² program must be directly tied to Army systems, but rather that a significant part must have this orientation. Clearly, some aspects of the program should be non-system directed to: (a) pursue innovative behavioral science technologies; (b) anticipate need of HF/C² roles further downstream; and (c) integrate and document HF/C² knowledge, methods, procedures, etc. for widespread use by the Army after they have been tested and successfully demonstrated by the ARI.

The framework is developed by defining dimensions that should be considered in identifying relevant HF/C² efforts of use to the Army. The first dimension is the HF/C² Role discussed in the previous section. For completeness, the roles are repeated below:

- HF/C² functional requirements
- HF/C² functional specification
- HF/ C² design
 - tasks
 - organizations
 - C² materiel
 - training

- HF/C² performance evaluation
- HF/C² performance prediction

The next dimension in the framework is the HF/C² Knowledge that is required to perform the HF/C² roles. Knowledge is defined as an understanding of the relationship between the degree to which a role is performed and the many factors (referred to as knowledge factors) which influence it. As an example, consider the role of designing the analysis/integration task performed by humans in an information processing center.¹ Information useful in performing this role would be knowledge of the relationships between measures of analysis/integration task performance and the following knowledge factors:

Cognitive factors:

- data characteristics
- types of decision processes and criteria employed
- perceptual and conceptual skills
- task loading

Work Station factors:

- data base size and content
- data entry modes
- data retrieval modes
- type of data display (medium, format, coding)
- decision aids for prompting, querying, processing
- general work station characteristics

¹Assuming the decision was made to perform this task by humans during the functional specification role for the system.

Organizational factors;

- size
- functional responsibility assignments
- span of control
- information flow

Training factors:

- kind of training anticipated (initial/maintenance, individual/unit)
- mode of training (classroom, simulation, field, etc.)
- frequency
- duration

Environmental factors:

- work station (noise, temperature, lighting)
- shock and vibration (movement related)

Although this example was intended to reflect knowledge requirements to design a C² task (analysis/integration), the same knowledge would be useful to guide design of the C² materiel/human interface to perform the task, training for the task, and the organizational aspects related to the task since these are explicit factors in the relationship.¹

Knowledge of this sort is needed for behavioral scientists to perform their HF/C² roles in the Army's system acquisition process, analogous to the engineer's use of physical science relations to select and design the materiel aspects of systems. Section 4.0 of this report

¹It is true that additional knowledge would be required to design an effective organization which encompassed many C² tasks and functions. Additional organizational factors that would have to be considered include the number of primary and support tasks involved, coordination requirements (frequency, duration, etc.), mobility requirements, redundancy, etc.

delineates a spectrum of relevant knowledge areas for the HF/C² analyst and provides initial subjective estimates of the degree of HF/C² knowledge available.

The Development Status of Systems is the third dimension of the HF/C² framework. A system can be in either a conceptual, development (validation, fullscale), or production/operational status, somewhat analogous to the acquisition phases. As will be shown later in the report, this dimension provides the means to indicate the relevance of ARI's HF/C² programs to specific system developments. The HF/C² roles required and when in the development cycle the roles must be performed are identified for each system requiring HF/C² support.

Exhibit 3-1 lists the status of a number of Army battlefield automated systems by function type, and some example estimates of the kind of HF/C² role(s) needed to support them and approximate times that the support must be provided.¹ Although ARI's responsibility encompasses procedural and organizational HF/C² issues in all Army systems, battlefield automated systems is used in this example to portray the requisite information pairing between an Army system's status and the HF/C² role because ARI's current emphasis is on HF/C² in automated systems. However, the development of ARI HF/C² research and analysis programs should explicitly consider HF/C² issues in manual and semi-automated systems (such as Patriot, Pershing II, CSWS²) and organizational ones (such as Division-86, the Fire Integration Support Team, CORPS-86, the infantry squad, etc.). Additionally, because of the

¹Times are listed where the estimate was deemed reasonable. An X is used to indicate that the role needs to be performed, but the time of performing it is uncertain.

²Some of these HF/C² activities may be performed by the appropriate ARI field unit.

EXHIBIT 3-1: REQUIRED HF/C² ROLES FOR SOME ARMY BATTLEFIELD AUTOMATED SYSTEMS

SYSTEM STATUS	FUNCTIONAL SYSTEM TYPE	HF C ² ROLE	FON POINTS	FON SPECS	DESIGN			PERF EVAL	PERF PPED
					TASKS	ORGN	1 st NAT.		
<u>CONCEPT:</u>									
<u>Intelligence:</u>									
	ASAS			31	33	33	34	36	37
	TCAC				32	32	32	33	34
	TACIES				34	34	34	33	34
	ELJ-TARLOCS	x	x						
	HAALS				x	x			
	RAWS				33	33	34	35	36
	ATRM	x	x						
	AMS								
<u>Command/Control:</u>									
	ECS ²			31	33	35	35	37	37
<u>Field Arty:</u>									
	APPS II				x	x			
	FMAS				x	x			
	BSSTAR				x	x			
<u>DEVELOPMENT:</u>									
<u>Intelligence:</u>									
	AGTELIS							32	
	SOTAS							32	
	TACELIS							32	
	Enhanced Guardrail							33	
	TEP				33	34		34	
<u>Command/Control:</u>									
	IBOS				x	x		x	
<u>EW:</u>									
	MULTENS				33			35	
	QUICK FIX							33	
	TACJAH							34	
	CASECM				33	33		35	
<u>Field Arty:</u>									
	ATPQ-36							33	34
	TPQ-37							33	34
	APPS-PTP							x	
	PAOS				x	x			
	BCS (BLC)				31		31	31	
	RPV				34	34		x	
<u>ADA:</u>									
	CCS				33	34		35	
<u>PRODUCTION:</u>									
<u>Intelligence:</u>									
	MAGIIC								
	QUICKLOOK II							32	33
	TRAILBLAZER							32	33
	CONFAC				32	32			
	GUARDRAIL I							31	32
<u>Field Arty:</u>									
	TACFIRE				31			32	32
<u>ADA:</u>									
	TSQ-73							x	

impact of early decisions on life cycle costs reflected in exhibit 2-3, the HF/C² program also should be designed to have influence on pre-concept phase system candidates.

The fourth dimension of the HF/C² framework is Type of ARI HF/C² Effort. Categories of this dimension are:

- Application Demonstration - the use of well-known HF/C² knowledge, methods, etc. to demonstrate how they are to be implemented in developing a system or system type. These are essentially 6.3a or 6.3b RDTE category efforts.¹ An example might be the use of span-of-control limits to assist in designing the organization of an ASAS.
- Applied Research - the application of general HF/C² knowledge to a specific system. In contrast to physical science relationships which usually can be applied directly in system design, most behavioral science relationships are thought of as hypotheses to be tested for applicability to specific system designs. An example might be the design of displays for an ASAS type system which would require an experimental project to ascertain if general hypotheses regarding human/display interactions were valid in the context of an ASAS environment. This type of ARI effort will usually be classified in the 6.3a RDTE program category.

¹The RDTE category of the ARI effort need not be related to the phase (i.e., conceptual, validation, etc.) and related program category (i.e., 6.1, 6.2, 6.3a, 6.3b, 6.4, etc.) of the system to which the results of the ARI effort are eventually applied. Thus, for example, an ARI 6.3a effort may be undertaken to support systems in the pre- or early conceptual phase and an ARI 6.1 basic research effort may be undertaken to support systems in production or deployed.

- Exploratory Research - the development of general HF/C² knowledge. Examples include the determination of research instruments to do some of the applied research¹ and a project to develop knowledge that would be useful in training humans to do effective order-of-battle intelligence processing. This type of effort will usually be classified in the 6.2 RDTE program category.²

The last dimension of the HF/C² framework is the First-Use Time Horizon. This is the time period before results (adequate knowledge) of a proposed or in-being ARI HF/C² project or program first would be used to support the development or operation of an Army system. Three categories of this dimension are deemed appropriate:

- Immediate: first use in 0-3 years
- Midterm: first use in 3-5 years
- Long term: first use in 5-10 years

Although not immediately apparent, the cartesian product of Type of ARI Effort and First-Use Time Horizon dimensions are possible, and not just the obvious combinations. An exploratory research project could produce information regarding some C² function that might be used immediately

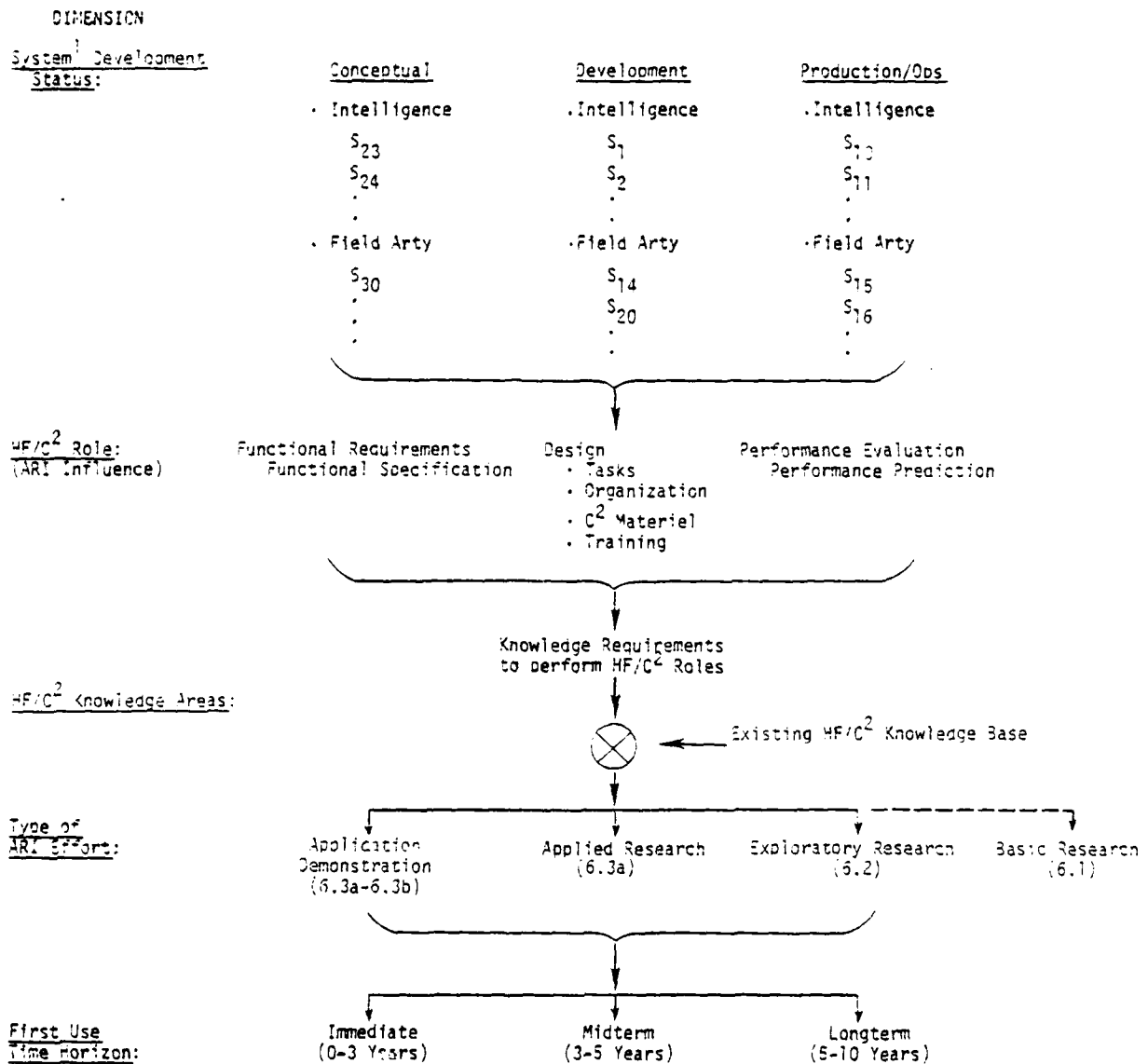
¹This example highlights the fact that some of the basic HF/C² research is not for the purpose of developing knowledge directly, but rather to develop methods/instruments for the knowledge research.

²As noted at the beginning of this section, some aspects of the ARI program will be non-system specific. Some of this non-system oriented work will have a less obvious link to HF/C² issues (e.g., researching innovative behavioral science technologies to explore potential utility for Army HF/C²) and accordingly, should be considered basic research in the 6-1 RDTE program category. (The distinction between 6.1 and early 6.2 efforts in DoD research organizations is at times not clear.)

(0-3 years) to suggest that the C² function be performed automatically in structuring a new system that is still in the conceptual phase. In a similar fashion, an applied or exploratory research project could generate organizational knowledge that could be used immediately to alter the organization of an existing system to improve its effectiveness.

In summary, the framework for identifying human factors research needs in the command and control area is comprised of five dimensions as shown in exhibit 3-2. It is a systems-oriented framework to depict where the HF/C² research programs have an influence on the Army, and to suggest that ARI's HF/C² program should be developed with a system's perspective to insure its relevance. Program development would follow the logic suggested in exhibit 3-2. ARI would continually track the status of Army systems requiring HF/C² support and identify specific HF/C² roles to be performed. HF/C² knowledge requirements to provide the support would be identified by analysis of the systems and the HF/C² roles. Comparison of these knowledge requirements with existing HF/C² knowledge would indicate the types of analysis/research efforts that might be included in ARI's HF/C² program.¹ The process of working through this paradigm to develop potential projects for ARI's HF/C² research and analysis program is demonstrated in section 5.0. The next section of the report expands the HF/C² knowledge area dimension and provides an initial estimate of the degree of such knowledge available for use in providing the Army with HF/C² support.

¹ The actual analysis/research program (by types of ARI effort required) would be developed with consideration of DA funding guidelines, system priorities, and the desired amount of non-systems-oriented research.

EXHIBIT 3-2: FRAMEWORK FOR IDENTIFYING HF/C² RESEARCH NEEDS

Specific systems are designated by the symbol S.

4.0 KNOWLEDGE AREAS IN HF/C²

The preceding sections of this report have outlined a five dimensional framework for determining human factors research and analysis needs in the area of command and control. This section discusses one of those dimensions, namely HF/C² knowledge, and is intended to indicate examples of the kinds of knowledge we believe necessary for effective performance of the different HF/C² roles described in Section 3.0 and to provide a preliminary estimate of the availability of HF/C² knowledge.

HF/C² knowledge was defined to be an understanding of the relationship between the degree to which a role is performed, and the many factors which influence it. In order to examine knowledge and factors in the context of command and control, we first propose a functional paradigm of the command and control process, that is, a decomposition of a generic command and control process into functions and the tasks which comprise those functions. We then discuss knowledge and knowledge factors relevant to each of the tasks included in the paradigm and include an estimate of the extent of knowledge currently available.

4.1 COMMAND AND CONTROL: A FUNCTIONAL PARADIGM

As noted earlier in this report, there is no commonly accepted definition of the command and control process, nor is there an agreed upon description of the components of the process. Broadly speaking, command and control is concerned with the collection of information, human assimilation of information, decision making, and the communication/dissemination of the decisions: elements which are present in varying degrees in all Army systems. A variety of functional descriptions of the

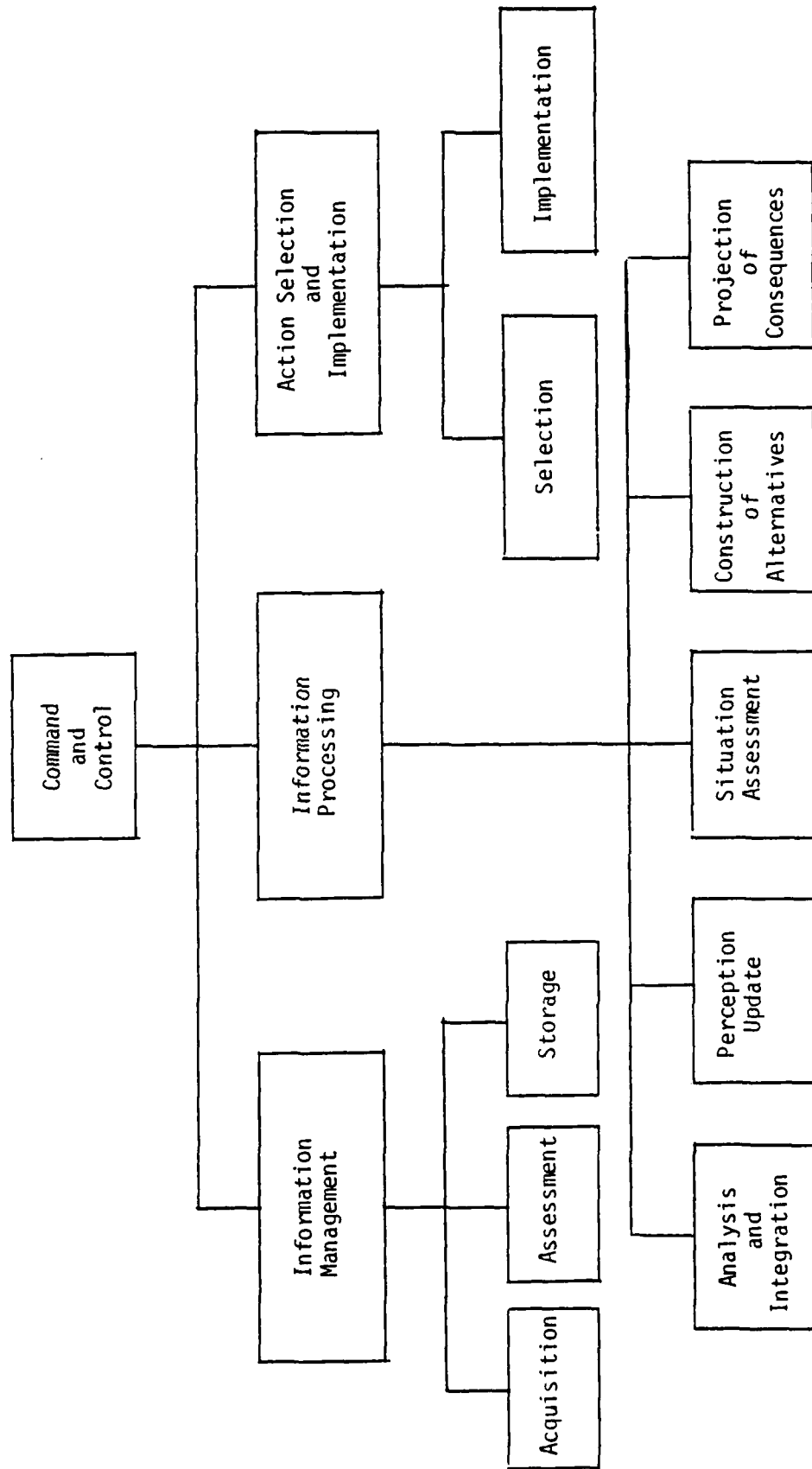
generic command and control process have been developed. One such description is illustrated in exhibit 4-1, based on research carried out to develop representations of command and control in models of combat. As illustrated in the exhibit, the command and control process is assumed to consist of three major functions:

- (1) Information Management;
- (2) Information Processing; and
- (3) Action Selection and Implementation.

Information management encompasses the acquisition of sensed or processed data by the command and control process, the initial evaluation or validity assessment of this data, and the storage and management of data in a generic data base or memory. Depending upon the level of the command and control process under consideration, information management could involve tasks ranging from a visual search of a portion of the battlefield to the employment of a division CEWI battalion, or the assessment of input data ranging from a blip on a radar screen to an intelligence summary from a subordinate brigade. The data base or memory in question could range from a hard copy intelligence journal with acetate overlays to an automated data base system with CRT displays.

Information processing is viewed as consisting of five major tasks. Analysis and integration is defined to be that task in which input data is correlated and fused with existing data to update the generic data base or memory. Perception update is the task in which processed data is incorporated into an updated perception of the battlefield: enemy forces, friendly forces, and the environment. Situation assessment is defined to be that task in which the dispositions, quantities and activities of friendly and enemy forces, as perceived, are

EXHIBIT 4-1: COMMAND AND CONTROL: A FUNCTIONAL PARADIGM



examined and projected into the future to identify requirements for new or revised plans, operations, or actions. Construction of alternatives is the task in which alternative courses of action are developed and specified as a consequence of requirements identified in the projection of the situation. The final task of information processing is the projection of consequences, in which the consequences of adopting any specified alternative are estimated by consideration of potential enemy activities and realizations of natural environments.

The third major function of the command and control process involves the selection of an action and subsequent implementation of the procedures by which subordinates are tasked, other entities are informed and/or activities are initiated. Selection of an action involves the application of criteria to the consequences developed for different alternatives and includes both the choice of a null action, (i.e., a decision not to decide or act) and a recognition of a requirement for further development of alternatives, (i.e., further information processing). Implementation of a selected action includes the development and communication of plans and orders throughout the command hierarchy. At the lowest levels implementation could be as simple as aiming and firing a weapon.

Dynamically, the process composed of the functions and tasks defined above should be viewed as operating continuously, with many functions and tasks carried out in parallel, rather than in series. Furthermore, as will be evident below in discussions of HF/C² knowledge, the distinctions between the various tasks can become blurred depending upon the numbers and responsibilities of personnel performing command and control.

Nonetheless, the paradigm does provide a basis for organizing the discussion of C^2 knowledge and knowledge factors.

4.2 HF/ C^2 KNOWLEDGE AND KNOWLEDGE FACTORS

As noted previously in this report, HF/ C^2 influences the development and operation of any system through performance of five roles:

- (1) HF/ C^2 functional requirements;
- (2) HF/ C^2 functional specification;
- (3) HF/ C^2 design:
 - (a) tasks;
 - (b) organizations;
 - (c) C^2 materiel;
 - (d) training;
- (4) HF/ C^2 performance evaluation; and
- (5) HF/ C^2 performance prediction.

Effective performance of the five HF/ C^2 roles depends upon the extent of available HF/ C^2 knowledge. HF/ C^2 knowledge is defined to be information regarding the relationship between degree to which relevant knowledge factors and the C^2 functions and tasks shown in exhibit 4-1 can be performed. The remainder of this section consists of a discussion of knowledge and knowledge factors required in the application of HF/ C^2 to the development and operation of systems which require command and control. The discussion will be based on the command and control paradigm presented above. Since knowledge to assist in performing the design role (tasks, organizational, C^2 materiel, and training) also provides knowledge to assist in the functional requirements and specification roles, these are considered simultaneously. The roles of performance evaluation and prediction are considered separately.

4.2.1 FUNCTIONAL REQUIREMENTS, FUNCTIONAL SPECIFICATIONS AND DESIGN KNOWLEDGE FACTORS

In a broad sense, there are five principal classes of HF/C² knowledge factors that influence the functional requirements, functional specifications and design HF/C² roles in the development of any system:

- (1) Cognitive;
- (2) Work Station;
- (3) Organizational;
- (4) Training; and
- (5) Environmental.

Cognitive factors fall into three principal categories. The first encompasses the individual's knowledge base, the types and sources of input required by the function or task under consideration and the outputs produced, including the effects due to the dynamics of combat. The second category includes personnel attributes associated with perceptual processes and skills, and the third involves the decision processes utilized internally in task performance.

Work Station factors are associated with man/machine interfaces and overall user/operator work station task procedures. In HF/C² analyses, these factors are related to system supports such as data base or memory enhancement and decision aids, and thus to factors such as data entry, data display, and data retrieval, in the context of the particular operator work station under consideration. Work station factors fall into two categories: user procedures which are usually considered to be ARI's responsibility, and hardware design which is usually considered to be HEL's responsibility.

Organizational factors include functional task assignments (both supervisory and production) to individuals, the specification of responsibility (span of control), information flow, and management procedures, and sizing. Combat imposes constraints and requirements on the organization of all units, and command and control organizations thus must include redundancy and be versatile to ensure adequate performance when damaged, dispersed, or severely stressed.

Training factors are those associated with establishing and maintaining required performance levels for personnel and organizations. Performance deficiencies in existing systems may be due to lack of proficiency, rather than lack of capability and as such are the province of the HF/C² analyst. Given any particular system the degree to which it accomplishes its objectives will depend upon the degree to which personnel have acquired and maintained proficiency in required skills, i.e., the degree to which training has been effective. Training factors thus consider such topics as initial training (skill acquisition) and proficiency retention training, individual and organizational training, frequency, duration, and mode (e.g., classroom, simulation, field exercise, etc.). Consideration of these factors is significant in the early stages of system development because of impact on life cycle cost and manning policies.

Environmental factors¹ are those associated with the impact of the physical environment on human performance, such as temperature, noise,

¹A significant portion of research in environmental factors is carried out by HEL and the Surgeon General.

lighting, etc. To some extent these factors can be controlled by appropriate operator/work station design, however, battlefield conditions may exceed design boundaries.

4.2.2 PERFORMANCE EVALUATION AND PREDICTION KNOWLEDGE FACTORS

As discussed in Section 3.0 of this report, in addition to performing HF/C² roles in Functional Requirements, Functional Specification and Design, the HF/C² analyst also performs roles in Performance Evaluation and Performance Prediction. These roles are performed in the latter stages of system development and deployment, and the degree to which they are accomplished successfully depends to a large extent on the degree to which cognitive aspects of tasks and task objectives have been defined during system design.

Performance evaluation is carried out to determine the degree to which an individual or organization will meet established standards of performance. Associated factors include the nature and performance standards of the task, consideration of differences between anticipated operational environment and evaluation environment, the entity evaluated (individual or organization) and the characteristics of the evaluation instrument.

Performance prediction factors are related to the ability to predict the degree to which an individual is capable of acquiring a particular skill or level of performance prior to or during training and thus emphasizes measurement of potential, i.e., in the identification of attributes and the relationship of attribute values to eventual performance levels. Performance prediction factors fall into two categories:

the first pertaining to knowledge of the human factors attributes required to perform a task; and the second pertaining to prediction instruments which measure these attributes.

The remainder of this section discusses knowledge factors in the context of the command and control functional paradigm presented above. Examples of cognitive, work station, organizational, training, and environmental factors common to the command and control tasks are listed in exhibit 4-2. The knowledge implied in this exhibit is to assist in performing the HF/C² functional requirements, functional specification, and design roles. Performance evaluation and performance prediction factors listed are considered in exhibits 4-3 and 4-4, respectively.

The knowledge requirements and knowledge factors presented in exhibits 4-2 through 4-4 are intended to indicate the kinds of information required by the HF/C² analyst to perform the HF/C² roles described in section 3.0 in the context of the tasks comprising the command and control process. As described in that section, these are used to identify potential ARI efforts (application demonstration, applied research, exploratory research) to either use or produce HF/C² knowledge. It is important to recognize, however, that at times there are insufficient methods, instruments, and/or information available to perform the knowledge generating research. Accordingly methodology development research may be necessary. For example, in assessing the impact of varying the quantity and quality of input data on the decision-making performance of a command and control system, it is first necessary to specify the input data used by the system. This specification may require research to determine what data is used before the research on variations of input data quality and quantity can be accomplished.

EXHIBIT 4-2: COMMAND AND CONTROL TASKS:
COMMON PERTINENT KNOWLEDGE FACTORS

Cognitive Factors:

Combat Dynamics/Status
Data Arrival Rates
Tasking

Personnel
Perceptual and
Cognitive Skills
Stress Thresholds
Motivation

Processing
Complexity
Domain

Data
Quantity
Quality
Variety

Work Station Factors:

Data Base
Size
Content

Data Display
Medium
Format
Coding

General Work Station
Characteristics

Data Entry

Decision Aids
Prompting
Querying
Processing

Data Retrieval

Organizational Factors:

Size
Span of Control
Information Flow
Redundancy

Task Assignments
Supervisory/Management/Coordination
Production

Training Factors:

Initial/Retention
Individual/Unit

Frequency
Duration
Mode

Environmental Factors:

Noise
Humidity

Radiation
Light

Atmosphere
Stress

Temperature
Shock/Vibration

EXHIBIT 4-3: PERFORMANCE EVALUATION: PERTINENT KNOWLEDGE FACTORS

- Evaluation Entity
 - Individual/Organization
 - Echelon
- C² Function/Task Evaluated
- C² Function/Task Performance Standards
- C² Function/Task Complexity
- Evaluation Environment
 - vs
 - Anticipated Operational Environment
- Evaluation Instrument
 - Type
 - Written Tests
 - Laboratory Experiments
 - Simulation
 - Games
 - Field Tests/Exercises
 - Characteristics
 - Reliability
 - Validity
 - Completeness
 - Evaluators
 - Objective
 - Subjective

EXHIBIT 4-4: PERFORMANCE PREDICTION: PERTINENT KNOWLEDGE FACTORS

- Function/Task Skill Requirements
 - Cognitive
 - Psychological
 - Physiological
- Prediction Instrument
 - Type
 - Reliability
 - Validity
 - Completeness

Similarly, before systems and procedures for performance evaluation¹ can be developed, research may be necessary to determine valid measures of C² performance. Thus, the factors presented are intended to provide insight not only into the efforts required by ARI to effectively influence Army command and control systems, but also into the research required to maintain and create the capability to accomplish those efforts. Such methodology development efforts most often will be in the exploratory research category, but may or may not be system oriented.

4.3 CURRENT AVAILABILITY OF KNOWLEDGE

The extent of HF/C² knowledge available for use in performing the HF/C² roles is needed as a basis for structuring ARI'S HF/C² research program. A taxonomy to categorize the degree of available HF/C² knowledge is described below.

- (D) Definitive: Sufficient HF/C² knowledge of a task (function) is available to perform HF/C² roles for that task (function) for all relevant system types and operating environments.
- (S⁺) Type System Specific: Sufficient HF/C² knowledge about a task (function) is available to perform HF/C² roles for that task (function) for the specific system type and operating environment.
- (S) System Specific, Methodology Available: Sufficient HF/C² knowledge about a task (function) is available to perform HF/C² roles for that task (function) for a specific subset of system types and operating environments not including those under consideration. Methodology is available to extend that knowledge to the system type and/or operating environments under consideration.

¹Evaluation of C² activities is discussed in the appendix to this report.

- (S-) System Specific, Methodology Unavailable: HF/C² knowledge about a task (function) is restricted to a subset of system types not including the type and operating environments under consideration. Methodology to extend knowledge to that type and/or operating environments is not available.
- (G+) General Knowledge, Methodology Available: The extent of HF/C² knowledge about a task (function) is limited to generally accepted hypotheses¹ evolving from general, non-system specific experiments. Methodology is available to produce knowledge to the degree required to perform HF/C² roles, for the specified system type.
- (G-) General Knowledge, Methodology Unavailable: The extent of HF/C² knowledge about a task (function) is limited to generally accepted hypotheses evolving from general, non-system specific experiments. Methodology to produce knowledge to the degree required to perform HF/C² roles for the specified system type is not available.
- (O+) Professional Opinion, Methodology Available: The extent of HF/C² knowledge about a task (function) is limited to generally accepted professional opinion. Methodology is available to conduct non-system specific experiments to produce general or more specific knowledge.

¹In contrast to physical science relationships which usually can be applied directly in system design, most behavioral science relationships are thought of as hypotheses to be tested for applicability to specific system designs.

(O-) Professional Opinion, Methodology Unavailable: The extent of HF/C² knowledge about a task (function) is limited to generally accepted, professional opinion. Methodology does not exist to conduct non-system specific experiments.

(V) Void: The extent of HF/C² knowledge about a task (function) consists of conflicting professional opinions.

Exhibit 4-5 summarizes the current status of HF/C² knowledge available to perform functional requirements, functional specification, and design HF/C² roles. This information was obtained in work sessions with ARI behavioral scientists who have been working in the HF/C² area for many years. The exhibit is organized by C² tasks and class of knowledge factor. The training factor class has been excluded deliberately as it was the opinion of ARI personnel that the impact of the training factor class, and successful performance of the other HF/C² roles of performance evaluation and performance prediction are all closely related to the extent to which task analyses can be or have been carried out, i.e., provided a learning objective has been identified, training programs, performance evaluation instruments, and performance prediction methods can be constructed using available methodology. It should be noted that dependence among knowledge factors classes is not restricted to the training factor class. Clearly the successful design of user work station procedures depends upon the extent of knowledge of the cognitive factors as does the incorporation of environmental factors and organizational issues into the determination of overall system characteristics and ultimate performance.

EXHIBIT 4-5: AVAILABILITY OF KNOWLEDGE

Knowledge Factor Class C ² Task	Cognitive	Work Station	Organizational	Environmental
Acquisition	G ⁻	G ⁺	O ⁺	S
Assessment	G ⁺	G ⁺	O ⁺	S
Storage	G ⁺	G ⁺	O ⁺	S
Analysis and Integration	G ⁻	G ⁺	O ⁻	S
Perception Update	G ⁺	G ⁺	O ⁺	S
Situation Assessment	G ⁺	G ⁺	O ⁺	S
Construction of Alternatives	O ⁻	G ⁺	O ⁻	S
Projection of Consequences	O ⁻	G ⁺	V	S
Action Selection	G ⁺	G ⁺	G ⁺	S
Implementation	G ⁻	G ⁺	O ⁻	S

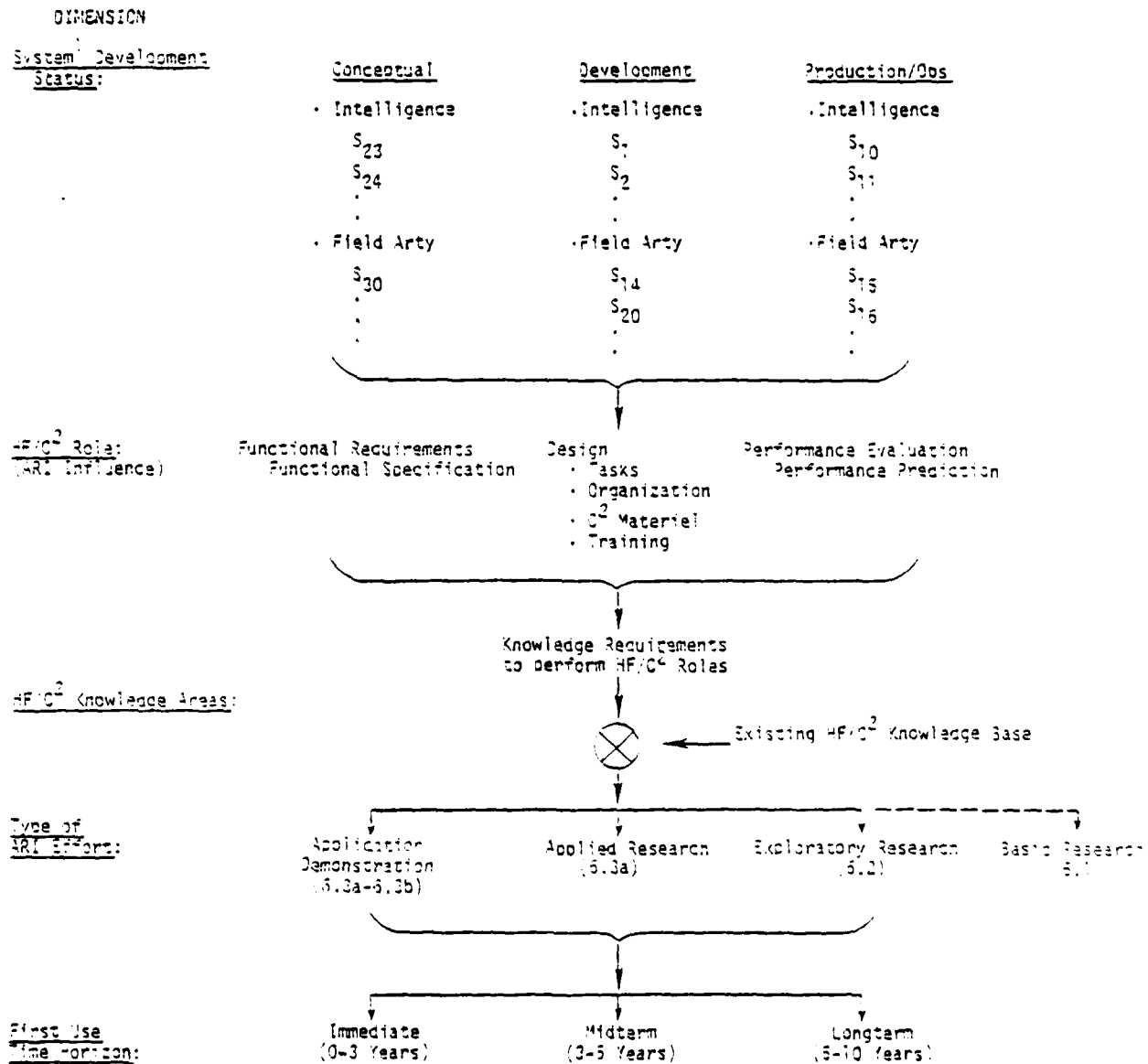
5.0 EXAMPLE FRAMEWORK APPLICATION TO IDENTIFY HF/C² RESEARCH EFFORTS

Section 3.0 of this report presented a systems-oriented framework for identifying human factors research needs in the command and control area in terms of five dimensions: System Development Status, HF/C² Roles (Influences), HF/C² Knowledge Areas, Type of ARI Effort, and First Use Time Horizons. HF/C² knowledge areas (by HF/C² functions, tasks and knowledge factors) and a scaling of the degree of HF/C² knowledge available was presented in section 4.0. In this section of the report we (a) show how the framework and available HF/C² knowledge are used to identify ARI research efforts needed to support the development of any system (section 5.1); and (b) demonstrate the process by identifying some HF/C² efforts relevant to the development of an All Source Analysis System (ASAS) (section 5.2). Since the paradigm can be used not only to develop the HF/C² program, but also to reflect the direct relevance of the program to the Army, some alternative means of presenting the research program using the framework information is given in section 5.3.

5.1 RESEARCH PROGRAM DEVELOPMENT PROCESS

The logic for developing the systems-oriented HF/C² research needs was schematically represented in exhibit 3-2. It is repeated in this section as exhibit 5-1 as an outline of the process recommended for ARI to develop their systems-related HF/C² research program. The steps in this process are defined below:

- (1) ARI should continually track the development status of Army systems (materiel, organizations), both those systems that are

EXHIBIT 5-1: FRAMEWORK FOR IDENTIFYING HF/C² RESEARCH NEEDS

Specific systems are designated by the symbol S.

designated as formal Army programs¹ (e.g., SOTAS, TACFIRE, BCS, AGTELIS, TACELIS, TACJAM, PATRIOT, PERSHING II, DIVISION-86) and those that are still in concept development (e.g., ASAS, TCAC, CSWS, ECS²). It should consider those in concept development which are advertised as moving rapidly through the development cycle to an early IOC date and those pre-natal developments that are just being formulated by Army laboratories, with potential IOC dates 10-15 years downstream.

- (2) For major systems or system types, ARI should identify what HF/C² Roles (functional requirements, functional specifications, design tasks, etc.) remain to be performed in developing the system and when in the development cycle they must be performed. (See exhibit 3-1 for the kinds of information envisioned in this stage of the process, although the exhibit does not contain many "pre-natal" systems.)
- (3) For each system-HF/C² Role pair identified, ARI should determine specifically what must be performed to accomplish the HF/C² Role for the specific system (or system type) and why the activity is needed (i.e., what would happen if not performed). Since the HF/C² Role may be performed by many different organizations (e.g., industrial contractors, TRADOC schools, a DARCOM laboratory, etc.) ARI must further identify what support it will provide to accomplish the needed HF/C² Role. This may vary from accomplishing the HF/C² Role

¹For this study we define formal Army programs as those that have passed ASARC I (or the equivalent stages for an organization's development).

entirely; providing methods, procedures, etc.; providing consulting support; monitoring the effort; to no participation.

- (4) For the support that ARI intends to provide in accomplishing the HF/C² Roles, it should identify the knowledge regarding HF/C² functions, tasks, and related knowledge factors¹ required to provide the support. The required knowledge should then be compared to the existing knowledge² base regarding the HF/C² functions, tasks, and knowledge factors to determine the type of ARI Effort³ needed to support the HF/C² Role. The suggested transformation to determine the Type of ARI Effort needed is shown in exhibit 5-2. The transformations reflected in the exhibit are based on the assumption that the required amount of knowledge available to accomplish an HF/C² Role increases as the role to be performed moves from functional requirements; to functional specification; to design of HF/C² tasks, organizations, etc. It is also implied that:

- exploratory research efforts are needed to generate general knowledge;
- applied research efforts are needed to produce system specific knowledge; and

¹See section 4.0 for a discussion of HF/C² functions, tasks, knowledge, and knowledge factors.

²See section 4.0 for a discussion of the existing knowledge categories.

³See section 3.0 for a discussion of Type of ARI Effort. Essentially these are potential projects for ARI's HF/C² research program.

EXHIBIT 5-2: DETERMINING TYPE OF ARI HF/C² EFFORT

<u>HF/C² ROLE</u>	<u>CATEGORY OF REQUIRED KNOWLEDGE</u>	<u>CATEGORY OF EXISTING KNOWLEDGE</u>	<u>TYPE OF ARI HF/C² EFFORT</u>
Functional Requirements	G ⁺	D, S ⁺ , S, S ⁻ , G ⁺	=> Application Demonstration
		G ⁻ , O ⁺	=> Applied Research
		O ⁻ , V	=> Exploratory Research
Functional Specifications	S	D, S ⁺ , S	=> Application Demonstration
		S ⁻ , G ⁺ , G ⁻ , O ⁺	=> Applied Research
		O ⁻ , V	=> Exploratory Research
Design • Tasks • Organizations • C ² Material • Training	S ⁺	D, S ⁺	=> Application Demonstration
		S, S ⁻ , G ⁺ , O ⁺	=> Applied Research
		G ⁻ , O ⁻ , V	=> Exploratory Research
Performance Evaluation		D, S ⁺	=> Application Demonstration
and	S ⁺	S, S ⁻ , G ⁺ , O ⁺	=> Applied Research
Performance Prediction		G ⁻ , O ⁻ , V	=> Exploratory Research

Legend: D : Definitive Knowledge
 S⁺: System Specific Knowledge for System Type under Consideration
 S : System Specific Knowledge for Related System Types,
 Methodology Available
 S⁻: System Specific Knowledge for Related System Types,
 Methodology Unavailable
 G⁺: General Knowledge, Methodology Available
 G⁻: General Knowledge, Methodology Unavailable
 O⁺: Professional Opinion, Methodology Available
 O⁻: Professional Opinion, Methodology Unavailable
 V : Void

- application demonstrations and applied research efforts on a large number of systems are needed to produce definitive knowledge about particular HF/C² functions, tasks, organizations, etc.

(5) The specific methodology used (e.g., experimental, survey, modeling, etc.) in accomplishing the application demonstrations, applied research, and exploratory research efforts derived in step 4 will depend on many factors including the amount of knowledge shortfall, costs, and schedule for accomplishment of the HF/C² Role within the system development cycle. The latter is contained in the systems status-HF/C² Role information determined in step 2 of the process and should be used to associate a First Use Time Horizon with each potential ARI HF/C² project.

In concluding this section, it should be recognized that the process described would produce a menu of potential projects for an ARI HF/C² research program. The actual program (i.e., proposed package of projects) would be developed with consideration of DA funding guidelines, system priorities, and amount of non-systems oriented research deemed necessary.

5.2 SAMPLE APPLICATION OF THE PROCESS FOR ASAS

In this section we demonstrate the process described above by preparing a sample worksheet for HF/C² research efforts related to development of an All Source Analysis System (ASAS). As noted in section 3.0, the ASAS is a system that is still in concept development, although

the Army is attempting to field it in the 1986-1987 time period.¹
 Exhibits 5-3 and 5-4 are sample worksheets for projects which support the functional requirements and design HF/C² Roles in development of the ASAS.

¹At the time of writing this report an industrial contractor was awarded a project to develop the functional system design (i.e., functional specifications) for the system prior to the end of 1980.

EXHIBIT 5-3: SAMPLE WORKSHEET -- FUNCTIONAL REQUIREMENTS ROLE

PROJECT: Human Factors

THRUST: Command and Control

RELEVANT SYSTEM: ASAS

REQUIRED HF/C² ROLE: Functional Requirements

The functional requirements for the All Source Analysis System are influenced by two major factors:

- (1) The necessity of fighting outnumbered requires that the commander be provided with information that is more timely, accurate, and extensive than that available from the current intelligence system.
- (2) Innovations in sensor technology and capability have greatly increased the amount of raw data available to the intelligence system.

These two factors lead to major HF/C² issues:

- (1) Command and control is a complex process varying across individuals. It is important to delineate what information is required, and the accuracy, timeliness and extent required of that information to respond to the needs of commanders.
- (2) Certain tasks (e.g., pattern recognition) are performed well by humans, while others can be automated, or supported by automation. Which tasks or functions in the intelligence process should be considered candidates for automation (replacement of manual implementation by ADP) or semi-automation (support of personnel by ADP), and which should be performed manually?

EXHIBIT 5-3: SAMPLE WORKSHEET - FUNCTIONAL REQUIREMENTS ROLE

(Continued)

(3) Automation and communication systems provide the capability to increase information flow and control. How should the personnel and support systems (e.g., automated data bases, decision aids, query features, etc.) best be organized to produce required intelligence, subject to the constraints and environment of military operations?

The functional requirements will be developed by TSM /ASAS with support provided by IBM.

HF/C² KNOWLEDGE REQUIREMENTS/AVAILABLE

The HF/C² knowledge required to accomplish the functional requirements role must fall into a category of General Knowledge, Methodology Available, or better. The current availability of knowledge relative to the ASAS is summarized in the following table. Comparison of this table to Exhibit 5-2 indicates that all of those cells that have an entry of G⁺ or better implies that information is available for direct application demonstrations. Cells indicating less knowledge imply topics or areas in which applied or exploratory research efforts are needed.

-- Continued --

EXHIBIT 5-3: SAMPLE WORKSHEET - FUNCTIONAL REQUIREMENTS ROLE
(Continued)

TABLE: AVAILABILITY OF KNOWLEDGE FOR ASAS FUNCTIONAL REQUIREMENTS

Knowledge Factor Class C ² Task	Cognitive	Work Station	Organizational	Environmental
Acquisition	G ⁻	G ⁺	O ⁺	S
Assessment	G ⁺	G ⁺	O ⁺	S
Storage	G ⁺	G ⁺	O ⁺	S
Analysis and Integration	G ⁻	G ⁻	O ⁻	S
Perception Update	G ⁻	G ⁺	O ⁺	S
Situation Assessment	G ⁺	G ⁺	O ⁺	S
Construction of Alternatives	O ⁻	G ⁺	O ⁻	S
Projection of Consequences	O ⁻	G ⁺	V	S
Action Selection	G ⁺	G ⁺	G ⁺	S
Implementation	G ⁻	G ⁺	O ⁻	S

EXHIBIT 5-3: SAMPLE WORKSHEET - FUNCTIONAL REQUIREMENTS ROLE

(Concluded)

TYPE OF HF/C² EFFORT REQUIRED

Performance of the functional requirements HF/C² role requires that knowledge fall in a category of general knowledge with methodology available to extend the knowledge to the system type under consideration. Due to the fact that current determination of functional requirements is being performed by a contractor, and the fact that the contract will terminate on 30 September 1980, all ARI participation in the functional requirements HF/C² role will consist of monitoring the contract and contributing via membership as an observer on the Study Advisory group. This effort, an application demonstration, will center on ensuring that available HF/C² knowledge is applied to the maximum extent possible and that potential problems requiring research are identified. Only one application demonstration work unit is required.

(1) Application Demonstration Work Unit: XXXXXXX

Project: _____

Principal Investigator: _____

Start Date: 1 February 1980

Objective: To ensure that HF/C² knowledge is applied in the development of Functional Requirements for the ASAS and to identify potential problems requiring HF/C² research.

Approach: Participation on ASAS FSD SAG as an observer.

Time for First Use: 1 February 1980

EXHIBIT 5-4: SAMPLE WORKSHEET - DESIGN ROLE

PROJECT: Human Factors
THRUST: Command and Control
RELEVANT SYSTEM: ASAS
REQUIRED HF/C² ROLE: Design

The design of tasks, material, organization and training for the intelligence analysis component in the ASAS system will have a major impact on the performance of the fielded system. Alternatives in the system currently in use have been limited. However, automation provides an opportunity to replace or support personnel involved in analysis tasks; furthermore, this approach may be necessary if increases in available raw information are to be exploited and intelligence needs met in the modern dynamic combat environment. The major HF/C² issues associated with the design of the intelligence analysis component(s) of the ASAS thus deal with task definition, organization, tradeoffs between automated, semi-automated, and manual implementations, and training. These issues cannot be addressed independently; moreover the design approaches eventually adopted will have significant impact on both cost and performance.

HF/C² KNOWLEDGE REQUIREMENTS/AVAILABILITY

The HF/C² knowledge required to accomplish the design role must fall into a category of system specific for the intelligence analysis component of ASAS. The current availability of knowledge relative to the intelligence analysis component is presented in the following table.

-- Continued --

EXHIBIT 5-4: SAMPLE WORKSHEET - DESIGN ROLE
(Continued)

TABLE: AVAILABILITY OF KNOWLEDGE FOR ASAS INTELLIGENCE
ANALYSIS COMPONENT DESIGN

Factor Task to be Designed	Available to Design Team	Available to Design Team with Access to Data Base	Available to Design Team with Access to Data Base and Analysis Tools	Available to Design Team with Access to Data Base and Analysis Tools and Expert System
Assessment	G ⁺	G ⁺	D ⁺	S
Storage	G ⁺	G ⁺	D ⁺	S
Analysis and Integration	G ⁺	G ⁺	D ⁺	S
Perception Update	G ⁺	G ⁺	D ⁺	S
Situation Assessment	G ⁺	G ⁺	D ⁺	S

EXHIBIT 5-4: SAMPLE WORKSHEET - DESIGN ROLE

(Continued)

Comparison of this table with exhibit 5-2 indicates that sufficient information exists on environmental effects for direct application demonstration. Knowledge available regarding cognitive, workstation and organizational factors suggests that applied and exploratory research efforts will be needed to complete the design.

TYPE OF HF/C² EFFORT REQUIRED

As is evident in the preceding table, the performance of the HF/C² role in designing the intelligence analysis component of the ASAS will require the initiation of a number of research efforts, both applied and exploratory, to extend general knowledge and professional opinion to ASAS system specific knowledge prior to the initiation of the design phase. The following potential projects would accomplish the necessary research.¹

¹The sample worksheet includes only two of the potential applied research projects. The actual worksheet would include all potential projects -- application demonstration, applied and exploratory.

EXHIBIT 5-4: SAMPLE WORKSHEET - DESIGN ROLE
(Concluded)

(1) Applied Research Work Unit: XXXXXXX

Project: _____

Principal Investigator: _____

Start Date: 1 August 1980

Objective: To identify the cognitive factors associated with intelligence analysis and determine procedures appropriate to intelligence analysis tasks.

Approach: Examination of Prototype TCAC and BETA systems, in the context of general cognitive psychology.

Time for First Use: 1 May 1981, in Design.

(2) Applied Research Work Unit: XXXXXXX

Project: _____

Principal Investigator: _____

Start Date: 1 January 1981

Objective: To develop a model of cognitive processes and factors in intelligence analysis tasks for use in design tradeoff analyses.

Approach: General cognitive psychology for model design, Monte Carlo implementation, interactive computer program.

Time for First Use: 1 August 1981, in Design.

5.3 PRESENTATION OF PROPOSED PROGRAM

Project worksheets similar to that presented in the previous section are the basic elements in developing the systems-oriented part of an ARI HF/C² research program. A large number of such worksheets would be developed to identify many potential projects for consideration in organizing the HF/C² program. As noted earlier, DA financial guidelines, system priorities, and other factors would influence the program composition proposed to DA. Recognizing that the process described in this report was designed to assist in developing an HF/C² program that is relevant to the Army, it also produces information that can be used to portray the relevance of ARI's HF/C² research program. Exhibits 5-5 through 5-12 are examples of the kinds of data that can be prepared for review by the DA staff, using the information inherent in the framework.

Exhibit 5-5 would provide an overview of all the Army's systems, by functional system type and their status in the development cycle, that were considered in developing the ARI HF/C² system-oriented research program. The influence that the HF/C² program is intended to have on a particular system, the total cost by type of relevant HF/C² effort, and when it is anticipated that the results of the ARI efforts will have an influence on the system is shown in exhibit 5-6. Similar exhibits would be available for each system listed in exhibit 5-5. Exhibits 5-7 through 5-11 are intended to show how the total ARI HF/C² systems-oriented program costs breakout by functional system type, acquisition phase of the influenced systems, the HF/C² influence (HF/C² roles), type of HF/C² effort in the research program, and when the results of the program would first be used to influence the development of Army systems.

Exhibit 5-12 depicts the structure of the ARI HF/C² non-system program by type of activity, specific project, and the costs by budget category.

EXHIBIT 5-5: ARI HF/C² SYSTEM PROGRAM

- OVERALL SYSTEMS RELEVANCE -

SYSTEM ACQUISITION STATUS

<u>Function System Type</u>	<u>Pre-Concept</u>	<u>Concept</u>	<u>Development</u>	<u>Production/Deployment</u>
Intelligence:	S24	ASAS TCAC HAALS . . .	AGTELIS SOTAS TACELIS . . .	COMFAC MAGIIC Guardrail V . . .
Command Control:		ECS ²	NBDS	
Electronic Warfare:		S27 S42 . . .	TACJAM QuickFix . . .	
Field Artillery:	S53	BSTAR FAMAS CSWS . . .	BCS PADS GSRS . . .	TACFIRE FIST . . .
ADA:	S60	S42 . . .	CCS Patriot . . .	TSQ-73
Maneuver Unit:	S71	DIV-86 Infantry Squad Corps-86 . . .		XM-1 . . .

EXHIBIT 5-6: ARI HF/C² SYSTEM PROGRAM
 - RELEVANCE TO SYSTEM S_i -

<u>HF/C² Role</u>	<u>Type of HF/C² Effort</u>	<u>Cost</u>	<u>Time of First Use</u>
Design Task			
1	Applied Research	\$	1983
2	Application Demonstration	\$	1981
•	•		•
•	•		•
•	•		•
Design Organization	Application Demonstration	\$	1983
Performance Evaluation	Exploratory Research	\$	1984
System S _i Total		<u> </u>	\$ _T

EXHIBIT 5-7: ARI HF/C² SYSTEM PROGRAM
 - COSTS BY FUNCTIONAL SYSTEM TYPE -

<u>Functional System Type</u>	<u>HF/C² Influence</u>	<u>Type of HF/C² Effort</u>	<u>Cost</u>
Intelligence:			
ASAS	Functional Specifications	Applied Research	\$
TCAC	Functional Requirements	Applied Demonstration	\$
.	.	.	.
.	.	.	.
.	.	.	.
			<hr/>
Intelligence Subtotal			\$ _I
Command Control:			
ECS ²	Functional Specifications	Applied Research	\$
S ₁₃	Performance Evaluation	Exploratory Research	\$
.	.	.	.
.	.	.	.
.	.	.	.
			<hr/>
Command Control Subtotal			\$ _C
Electronic Warfare:			
TACJAM	Design Task 3	Applied Research	\$
QuickFix	Performance Evaluation	Application Demonstration	\$
.	.	.	.
.	.	.	.
.	.	.	.
			<hr/>
Electronic Warfare Subtotal			\$ _{EW}
.	.	.	.
.	.	.	.
.	.	.	.
			<hr/> <hr/>
Total			\$ _T

EXHIBIT 5-8: ARI HF/C² SYSTEM PROGRAM

- COSTS BY SYSTEM ACQUISITION PHASE -

<u>System Acquisition Phase</u>	<u>HF/C² Influence</u>	<u>Type of HF/C² Effort</u>	<u>Cost</u>
Pre-Concept:			
S ₄	Functional Requirements	Application Demonstration	\$
S ₃	Functional Specifications	Applied Research	\$
.	.	.	.
.	.	.	.
Pre-Concept Subtotal			\$ _P
Conceptual:			
ASAS	Functional Specifications	Applied Research	\$
BSTAR	Design Acquisition Task	Applied Research	\$
S ₂	Design Organization	Applied Research	\$
.	.	.	.
.	.	.	.
Conceptual Subtotal			\$ _C
Development:			
SOTAS	Performance Evaluation	Application Demonstration	\$
Patriot	Performance Evaluation	Applied Research	\$
.	.	.	.
.	.	.	.
Development Subtotal			\$ _D
Production/Deployment:			
TACFIRE	Performance Evaluation	Application Demonstration	\$
.	.	.	.
.	.	.	.
Production/Deployment Subtotal			\$ _E
Total			\$ _T

EXHIBIT 5-9: ARI HF/C² SYSTEM PROGRAM
 - COSTS BY HF/C² ROLE (INFLUENCE) -

<u>HF/C² Influence</u>	<u>Type HF/C² Effort</u>	<u>Cost</u>
Functional Requirements:		
S ₁	Application Demonstration	\$
S ₂	Exploratory Research	\$
S ₃	Applied Research	\$
.	.	.
.	.	.
.	.	.
Functional Requirements Subtotal		\$ _R
Functional Specifications:		
S ₆	Applied Research	\$
S ₁₂	Application Demonstration	\$
.	.	.
.	.	.
.	.	.
Functional Specifications Subtotal		\$ _S
Design Tasks:		
S ₂₃	Applied Research	\$
S ₁₂	Applied Research	\$
.	.	.
.	.	.
.	.	.
Task Design Subtotal		\$ _D
.	.	.
.	.	.
.	.	.
Total		\$ _T

EXHIBIT 5-10: ARI HF/C² SYSTEM PROGRAM

- COST BY TYPE OF EFFORT -

<u>Type of HF/C² Effort</u>	<u>HF/C² Influence</u>	<u>Time of First Use</u>	<u>Cost</u>
Application Demonstration:			
S ₁	Functional Specifications	1981	\$
	Design Organization	1982	\$
S ₃	Design Situation		
	Assessment Task	1980	\$
	Performance Prediction	1983	\$
.	.	.	.
.	.	.	.
Application Demonstration Subtotal			<u>\$_D</u>
Applied Research:			
S ₁	Design Task 4	1982	\$
S ₂₃	Performance Evaluation	1984	\$
S ₄₀	Performance Evaluation	1983	\$
.	.	.	.
.	.	.	.
.	.	.	.
Applied Research Subtotal			<u>\$_A</u>
Exploratory Research			
S ₂₄	Functional Requirements	1984	\$
S ₃₀	Design Organization	1987	\$
.	.	.	.
.	.	.	.
.	.	.	.
Exploratory Research Subtotal			<u>\$_E</u>
Total			<u><u>\$_T</u></u>

EXHIBIT 5-11: ARI HF/C² SYSTEM PROGRAM

- COST BY FIRST USE HORIZON -

<u>First Use Horizon</u>	<u>HF/C² Influence</u>	<u>Cost</u>
Immediate (0-3 years)		
S ₁	Design Task 3	\$
S ₃	Performance Evaluation	\$
S ₅	Functional Requirements	\$
.	.	.
.	.	.
.	.	.
	Immediate Use Subtotal	<u>\$_I</u>
Midterm (3-5 Years)		
S ₂	Design Organization	\$
S ₄	Design Task 7	\$
S ₁₂	Performance Evaluation	\$
.	.	.
.	.	.
.	.	.
	Midterm Use Subtotal	<u>\$_M</u>
Long Term (5-10 Years)		
S ₃₁	Functional Requirements	\$
S ₃₂	Functional Specifications	\$
S ₃₃	Design Organization	\$
.	.	.
.	.	.
.	.	.
	Long Term Use Subtotal	<u>\$_L</u>
	Total	<u><u>\$_T</u></u>

EXHIBIT 5-12: ARI HF/C² NON-SYSTEM PROGRAM

<u>Type Activity</u>	<u>Specific Project</u>	<u>Cost</u>	
		<u>6.1</u>	<u>6.2</u>
A. Integrate/Document HF/C ² System Methodology	1. _____		\$
	2. _____		
	3. _____	\$	
	.	.	.
	.	.	.
B. Explore Behavioral Science Technologies ₂ for Application to C ²	1. _____	\$	
	2. _____	\$	
	3. _____		\$
	.	.	.
	.	.	.
C. Perform Research in Anticipation of HF/C ² Needs	1. _____	\$	
	2. _____	\$	
	3. _____	\$	
	.	.	.
	.	.	.
.	.	.	.
.	.	.	.
.	.	.	.
Sub-total Non-System		<u>\$6.1</u>	<u>\$6.2</u>
Total Non-System		<u><u>\$_T</u></u>	

6.0 GENERAL COMMENTS

Previous sections of this report described a framework that could be used to identify human factors research and analysis needs in the area of command and control. This final section presents some brief comments, somewhat tangential to the rest of the report, but with a similar objective -- that of identifying command and control research and analysis activities which, when conducted, will improve the operational capabilities of the Army.

Anyone who has been in the field with operational units recognizes that there is a multiplicity of command and control problems, and that a research framework is not essential to their identification. Command and control problems exist within the tank crew, the infantry squad, the tank platoon, the G-2 and G-3 shops, the fire direction center, air defense fire units, and other Army systems that must collect information, assimilate it, make decisions, and communicate the decisions. Rather, the difficulties appear to be that:

- (1) there is no organized approach to the identification of relevant HF/C² analysis and research programs that senior managers would deem relevant to accomplishment of Army missions, and
- (2) there is no vocal constituency within the Army that is actively raising the Army's consciousness of existing and potential command and control problems and proposing efforts to develop solutions.

The framework described in this paper may be useful in rectifying the former. We believe ARI's work in the HF/C² area has perhaps been too passive with respect to both of the above difficulties, and accordingly, offer the following suggestions for consideration:

- (1) ARI must actively identify where significant HF/C² problems exist (or may arise downstream) with operational, developmental, and conceptual systems. All major Army systems should be tracked continually regarding the status of HF/C² support provided and needed (i.e., status of the HF/C² role dimension). Problem identification emphasis should be placed on identifying where the absence of such support results in current or near-term problems.
- (2) The HF/C² performance evaluation role must provide feedback on the efficacy of the HF/C² design efforts. The ARI field offices should be the principal providers of this feedback by identifying HF/C² "lessons learned" from reports of previous battles (e.g., Sinai battles) and HF/C² problems observed in field exercises. This information should be an integral input to development of the HF/C² research and analysis program.
- (3) ARI should develop an organized and dynamic HF/C² research and analysis program using a framework similar to that described in sections 3.0 to 5.0 of this report. The program should evolve continually and reflect its utility by documenting the Army systems it has influenced and the relevance of proposed HF/C² efforts to developmental and conceptual systems. This may require the development of a "systems HF/C² status" data base (i.e., what has been and ought to be done) and an "HF/C² knowledge area" data base for use in both developing and documenting ARI's HF/C² program.

- (4) Identification of command and control problems by ARI and an organized HF/C² study program is necessary, but not sufficient, to build a viable HF/C² program. ARI must actively work on raising the awareness and perception of Army managers that such problems do exist, they have associated effectiveness (or cost) ramifications, solutions can be developed to resolve them, and that ARI has an organized ongoing program to develop such solutions. Using private sector vernacular, ARI must "market" and "sell" the idea that HF/C² research and analysis is relevant, important, feasible, and useful. If possible, it would be useful to document a small number of HF/C² "success stories" in the framework format.
- (5) The Army's physical science laboratories are continually advancing new technologies, either to resolve a recognized problem or propose new capabilities for the operational forces. In an analogous fashion (and consistent with an active HF/C² program), ARI should continually search¹ for and advance new behavioral technology applications as opportunities for the Army to pursue (e.g., self training systems).
- (6) As noted earlier in this report, both ARI and HEL are involved in providing HF/C² support for the acquisition of Army systems. Although the distinction is not precisely defined, HEL appears to be concerned with operator/machine HF interface issues and ARI's human factors group with HF/C² procedural/organizational¹ aspects to assist users (e.g., commanders, G-2, G-3, etc.)

¹Outside the defense area or as part of the non-system related HF/C² research and analysis program.

of Army systems. HEL is active in implementing their research efforts to assist in the development of Army systems. In contrast, ARI appears to have interpreted its principal role (described in AR 602-1, AR 70-8, and AR 70-1) as one of developing HF/C² knowledge/methodology and demonstrating it, but not the active use/implementation of HF/C² knowledge/methodology in the development of Army systems. Because:

- we are unable to identify an organization of trained behavioral analysts in the Army that is using the procedural and organizational HF/C² knowledge/methodology to assist in the development of Army systems;
- senior managers in the Army continue to stress the importance of effective command and control as a major ingredient in Army units; and
- Army regulations do not appear to preclude it;

we believe that the ARI HF/C² program should more actively contribute to the development of major Army systems by performing (or assisting in performing) the functional specification, design (tasks, organization, etc.) and performance evaluation activities described in section 2.0 of this report.

This will require more active participation in both the conceptual and validation phases of a system's development.

Paragraph 3-4 of AR 70-8 explicitly indicates that ARI should participate in Advanced Development (6.3A) activities which "...involve the application of scientific knowledge...to current or potential field problems" (paragraph 1-7b).

Paragraph 3-4f indicates that the developing agency should turn

the end product of 6.3A RDTE activities over to the using/operating agency for implementation. However, because such implementations of HF/C² knowledge and methods do not appear to be occurring, we believe that (as suggested at the end of paragraph 3-4f) ARI should more actively assist users in the implementation process to develop effective C² procedures, organizations, training, etc. for major systems.

APPENDIX: APPROACHES TO EVALUATING COMMAND-CONTROL SYSTEMS

Command-control systems, which may be entirely human or mixed man-machine systems, must be evaluated in many ways during the development, procurement, and use process. Evaluators may be concerned with evaluating the total marginal cost of the systems, their logistic demands, their maintenance demands, their reliability, their failure modes and capability to provide adequate continuity of operations, the training and other personnel requirements associated with the system, and/or the functional performance of the systems in their major roles. This appendix is concerned only with the problem of evaluations of command control systems with respect to their functional performance. It discusses some of the major issues related to the choice of an approach to the evaluation problem. It does not address the detailed problems of implementation of specific approaches; there is a sizeable literature already in existence addressing the evaluation and analysis of human or man-machine information processing systems, and this appendix cannot provide coverage of the voluminous material which has been published on the detailed problems in the evaluation process. Rather, it provides an overview of issues which bear on the choice of an overall approach to an evaluation. These issues will be discussed in terms of major dimensions of evaluation approaches, where an approach can be defined in terms of the choices made in terms of these dimensions.

Nine of these major dimensions will be discussed in this appendix.

They involve:

- (1) the contrast between unitary and partial approaches to system evaluation,
- (2) the dimension running from the use of measures of military effectiveness to the use of system performance measures,
- (3) the distinction between approaches which involve the evaluation of a command-control system on individual tasks and those which evaluate a system on a realistic stream of tasks,
- (4) the contrast between those approaches intended to provide a quality assessment from those intended to provide diagnostic information for system design, redesign, or optimal use,
- (5) the distinction between approaches which involve an absolute evaluation of one or more systems and those which involve only comparative evaluation of two or more systems,
- (6) the dimension extending from approaches involving evaluation during real system use to approaches involving evaluation based on theoretical models of the system,
- (7) the distinction between observation- or measurement-based evaluations and those based on participant reporting,
- (8) the contrast between objectified and judgmental evaluation techniques, and
- (9) the dimension which describes the detailed indices being used the the evaluation.

The first of these dimensions which is discussed contrasts unitary and partial approaches to command-control system evaluations. In a

unitary approach, the system is examined or modelled in its entirety (or very nearly so); in a partial approach, the system is divided into functionally or physically separated subsystems, and these are evaluated separately. A compound approach is also possible, in which the system is experimented with or modelled in entirety, but measurements are taken and examined in ways designed to estimate the performance of the subsystems.

Generally, the partial approach is less expensive to implement but leaves serious risks of misevaluation of the total system through neglect of unforeseen interactions among subsystems. It is also sometimes difficult to identify appropriate subsystems for separable evaluations. The unitary approach does not involve the identification of subsystems and separate subfunctions, but also cannot be used to provide information which will help system designers improve the various elements of the system separately. The compound unitary-multipart approach requires probably the greatest effort, both preparatory (in terms of identifying and analyzing subsystems and subfunctions) and in accomplishment (in terms of the expenses of experiment or simulation).

Examples of the types of approaches distinguished here may be seen in a hypothetical evaluation of an artillery command-control system. A unitary approach would involve experimentation and/or simulation of the entire multi-person, multi-machine system in an appropriate environment and the estimation of overall performance measures. These measures might include such scales as fraction of targets attacked, predicted casualties caused, etc. Partial approaches might separate several of

the types of functions being performed (e.g., storage and retrieval of target information, selection of targets for fire, computation of parameters for fire missions against targets, communication of missions to batteries). Separate models or experiments could then be used to analyze each of these functions (or a different set of subfunctions or subsystems, e.g., a separation of the human portion of the system from the machine portion) in terms of individual performance measures such as time required to enter target information, probability of timely retrieval of target information, fractions of high-priority and low-priority targets fired on, appropriateness of fire mission computations for selected targets, communication delays between fire mission computations and battery receipt of firing order, etc. A compound approach would involve aspects of both methods.

Another dimension which describes alternative approaches to the evaluation of command-control systems is the dimension which runs between extremes one of which uses measures addressing military utility and the other of which uses measures of system performance. At the extreme level, military utility measures address an estimate of overall force effectiveness; the lowest level of system performance measures address such micro-issues as the average time between a query or directive to a machine component and the response or accomplishment. Although often associated in practice with the unitary-partial dimension, this dimension is actually a distinct area. It is possible to have military utility measures in a partial approach or system performance measures in a unitary approach, as well as the more usual patterns. Examples in an air-defense command-control area might be the comparison of two target selection algorithms in terms of the predicted mean number of penetrating aircraft (considered as part of a specified

raid) which would deliver their ordnance on a target, or the comparison of two overall systems in terms of the mean range at which target aircraft were first engaged.

This dimension is not binary, and in some cases it is not clear where some measures fall. (The mean range at first engagement measure was used above as an example of a system performance measure -- to some analysts, this might be considered a military worth measure.) Even though the dimension is neither binary nor perfectly defined, it is a useful dimension for distinguishing approaches. In choosing an approach, the use of either extreme should be avoided. Measures addressing very high-level military utility provide little diagnostic information to system analysts and designers and are highly dependent on assumptions, models of various effects, and environmental conditions. System performance measures alone may be seriously misleading in the frequent cases in which military utility is little effected (or effected in a highly non-linear pattern) by the system performance of concern. An approach using middle-level measures or a package of measures including both system-level and military-utility level scales is preferable to either extreme alone.

Both these first two dimensions have been different ways of describing the degree of holism of an approach. There is a third dimension which also concerns the degree to which an approach is holistic, but in yet a further distinct way. This third dimension involves the distinction between the assessment of command-control systems on individual tasks and their assessment on a realistic stream of tasks. A fire-control system might be assessed, for example, on a problem defined in terms of a single target and associated fire mission (or a single group of targets and multiple fire missions), or in terms of a realistic time-line of activities including both periods with few

activities and other periods with single and multiple tasks overlapping in realistic ways. This type of evaluation addresses not only task performance on well-defined tasks but also the capability of the individual or staff organization, with whatever machine support is provided, to appropriately structure tasks in an unstructured environment. To some extent, this dimension associates with the distinctions often made between "free-play" exercises and evaluations and "structured" exercises. For most command and control systems, it is critical that at some points both early and late in their development cycle they be evaluated (and designed to handle) the realistic, unstructured stream of tasks representing the situations in which they will actually be employed. On the other hand, throughout the middle of their development life, structured evaluations generally provide clearer feedback to the developers and designers on development and design issues, and are therefore preferable. To some extent, this same general tendency is observable in all of the three holism dimensions described here. Unitary and military utility approaches are more useful near the beginning and end of development programs, while partial and performance-oriented approaches provide better detailed guidance to designers and developers during the middle of the development process.

These observations concerning the differential utility of more and less holistic approaches at different phases of development in fact bring out another dimension on which evaluation approaches may be contrasted. This dimension involves distinguishing evaluations intended to serve in a quality-assessment role from those assessments which are intended to provide diagnostic information suitable to guide designer, developer, or user actions into the most profitable channels. Quality

assessments of designs are generally used in development processes at the very early, concept definition phases, so that potential overall impact may be assessed before committing even to the development process, and at the late stages, when the system is in a well-developed state and one wishes to test the degree to which early expectations have been met so that a reasoned decision on procurement can be made. (In the current Army development process, quality assessments are also associated with certain mid-cycle decision points.)

Diagnostic examinations are useful in the early, concept definition phases and throughout the middle of the development process. In the early phases, diagnostic examinations provide information on design directions in what is at that point still a vaguely-defined product. After a commitment to development along the lines of a particular design, diagnostic evaluation permits the examination of alternative design approaches within the general design selected in the early phases.

Another dimension on which approaches may be contrasted, still in the general area of the intention of the evaluation, is that which contrasts absolute evaluations with comparative evaluations. Absolute evaluations are generally used to examine the performance of systems in terms of measures or criteria which are stated in a fashion making no reference to alternative systems. Comparative evaluations involve inherent comparisons with alternative systems. Thus, for example, an evaluation of a command center support system against the standard "it must allow performance of all functions with 20% fewer staff than the present system" is inherently comparative. In choosing an evaluation

approach, the principal concern in this area is that the approach correspond to the actual intentions of those who will be using the results of the evaluation.

The remaining dimensions have to do with the types of methods and measurements used in evaluations rather than with the degree of holism or the intentions of the evaluation. The first of these remaining dimensions is that which contrasts, at one extreme of a continuous scale, evaluations conducted on systems during real use with, at the other extreme, evaluations performed by theoretical modelling and inference. In the area of developmental command and control systems, making observations of a system in real use is generally impossible. The closest achievable case is usually either evaluation in field trials or in field experiments, possibly with simulations of some or all of the environment of the system. There are many discussions available which address the relative values of approaches on different points of this dimension, which includes laboratory testing, detailed simulation, and completely theoretically-based evaluations at the more abstract end of the scale, and the arguments for and against these techniques are basically the same in the command-control systems area as in other areas. Accordingly, this report will not contain any further discussion on these topics.

Another dimension, which is more closely related to the command-control area, contrasts approaches which use observation and measurement techniques from those which rely on participant reporting on a system. In this area as in most, observational techniques, in which the evaluations of a system are made by persons independent of the operations, are generally preferred for their objectivity. Another

dimension which is often confused with this one, but is in fact a distinct dimension of evaluation approaches, is that which contrasts objectified evaluations with judgmental ones. Judgmental observations made by an observer are significantly different than judgmental observations made by a participant in a command-control system. Further, participant observations may be used even when objectified measures are used. As with other dimensions, this objectified-judgmental dimension is not binary, but has middle areas in which objectified scales which are simply formal representations of judgment are used. Generally, objectified methods are preferred, although judgmental techniques may often shed diagnostic light on possible design changes or unforeseen possible uses (or detriments) of a system.

The last dimension discussed here (and perhaps the most important) is the dimension which describes the measurement indices which are used in the evaluation. It is not possible here to describe all, or even a major fraction of the possible indices in detail. Instead, they are described in terms of three general types of index: those which deal with timing aspects of the system performance, those which deal with procedural aspects of performance, and those which deal with substantive measurements of performance. (Indices which combine these aspects are also possible, of course.)

Indices which deal with timing aspects, such as delays or measurements of the time required to perform certain tasks, are easily recognized. Their overall usefulness depends on the degree to which the eventual military utility of the system depends on the timeliness of the task performance (and the degree to which alternative systems show

variations in timeliness).

Examples of indices which deal with procedural aspects are such measures as the fraction of users who issued proper orders for fire missions, or included all necessary information in messages calling for close air support, or the percentage of brigades for which situation information is properly stored, etc. These indices are most useful in evaluating command-control support systems which are designed to reduce errors and confusion in operations, or to make staff tasks easier. For systems with clear decision support roles, it is generally more useful to use substantive indices of the appropriateness of the decisions made.

Substantive indices involve attempts to measure the functional performance of the system in more direct ways. Typical indices in this approach might include the fraction of identifiable targets which were identified, or the fraction of retrieved reports which were in fact relevant to a request, or the fraction of relevant reports which were retrieved, or the fraction of critical decisions which an independent panel reviewing a reconstruction of an exercise or experiment considers to have been significantly wrong decisions, etc. These indices are generally important in the evaluation of decision-support systems, although timing and procedural indices may be equally critical even in these contexts.